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TITLE

D. C. VOLTAGE MULTIPLIER

ABSTRACT

The d-c voltage multiplier is a means of obtaining high direct current voltages. The system consists of charging a group of capacitors, all permanently connected in series, to a definite voltage. The addition of these individual voltages give the high voltage. The amount the voltage is stepped up depends upon the number of capacitors used and the charging rate. The resulting output voltage has very good regulation at small loads.

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CONCLUSIONS

The construction and tests of the d-c voltage multiplier have proved that the system is practical and with some improvements on the present design, will be an inexpensive, compact, and stable means of producing high direct current voltages.

For list of contents—drawings, photos, etc. and for distribution see next page (FN-610-2).

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TESTS MADE BY C. Q. Lemmond

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COUNTERSIGNED C. M. Foust C M Foust Sept 1, 1949

DIVISIONS High Voltage and Nucleonics Division LOCATION Schenectady, New York

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DRAWING NOS. PH-9633598, KH-9633599, KH-9636400, KH-9636401, KH-9636402, KH-9636403, KH-9636404, KH-9636405, KH-9636406

PHOTO NOS. 1069461

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D. C. VOLTAGE MULTIPLIER

Introduction

There are several means of producing high direct current voltages. Most consist of stepping up a low voltage with transformers or oscillators and rectifying the resultant voltage. These methods are usually fairly expensive and require considerable bulky equipment. The system presented here requires no electronic tubes, produces a high voltage in definate gradation, has a good regulation at low current drains, and is much less costly than the other methods mentioned.

Description of Operation

The d-c voltage multiplier is a means of stepping up direct current voltages to higher values. The basic principle of operation consists of connecting a number of capacitors in series and charging each to a definate voltage. If the individual voltages are maintained at the original charged value by repeated charging, the total voltage (E) across the bank is equal to the individual voltage (V_c) times the number of condensers (N).

$$E = N\ V_c$$

The rate at which the capacitors must be re-charged is determined by the current drain and the leakage. As the load increases, the voltage ripple also increases. This means of obtaining high d-c voltages is most applicable, therefore, where low current drains are employed. Several applications of the d-c voltage multiplier were tried and proved to be very successful.

The model shown in photograph number 1069461 is constructed with 100 -0.5 microfarad capacitors in each of the two legs. Each capacitor is charged to a voltage of 1000 volts. The total capacity between the output terminals is 0.01 microfarads and the voltage output is 100,000 volts.

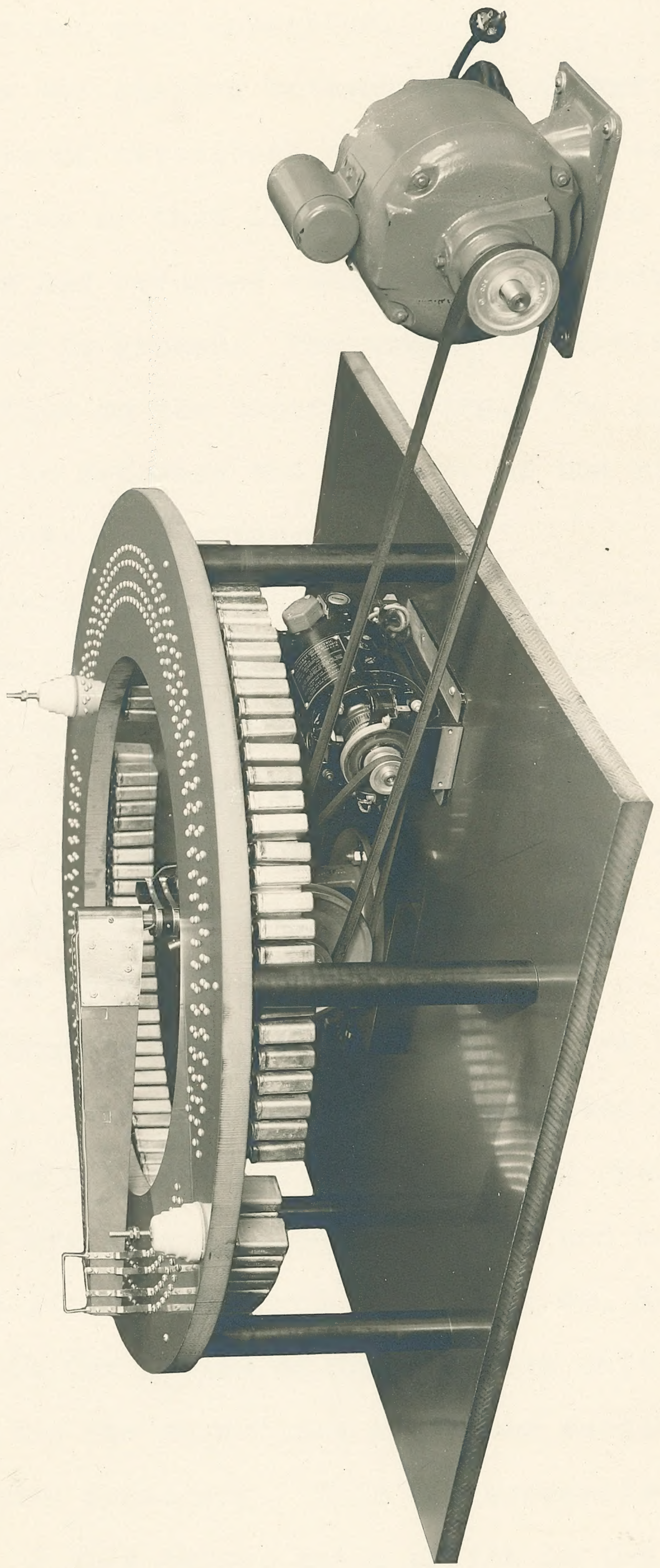
The system is powered by a 3/4 horsepower motor, which turns a 1000 volt generator, and the charging arm. The arm sweeps over each capacitor once per second and maintains a charge of 1000 volts on each capacitor.

Design Considerations

The unit constructed was designed for compactness, availability of components, and for the most economical means of obtaining the desired result.

The first consideration was that of obtaining the 1000 volts used to charge the capacitors. Any method would necessarily have to "float" from ground potential up to 100,000 volts, since every step of the charging cycle increases the potential of the brushes above ground. Voltage rectifiers were eliminated because of the insulation problem. The use of batteries was a possibility, but a method of holding a constant d-c potential was considered more practical. A belt driven generator was finally decided upon and a war surplus dynamotor was obtained at very little cost. The generator proved to be very practical as it could "float" above ground and there was no difficulty experienced in holding the same output voltage after many hours use.

A mechanical means of charging the capacitors was then considered. The best method seemed to be an arrangement of capacitors



1069 461 DIRECT CURRENT VOLTAGE MULTIPLIER FOR PRODUCING 100,000-VOLTS.

E369.9 6-9-49

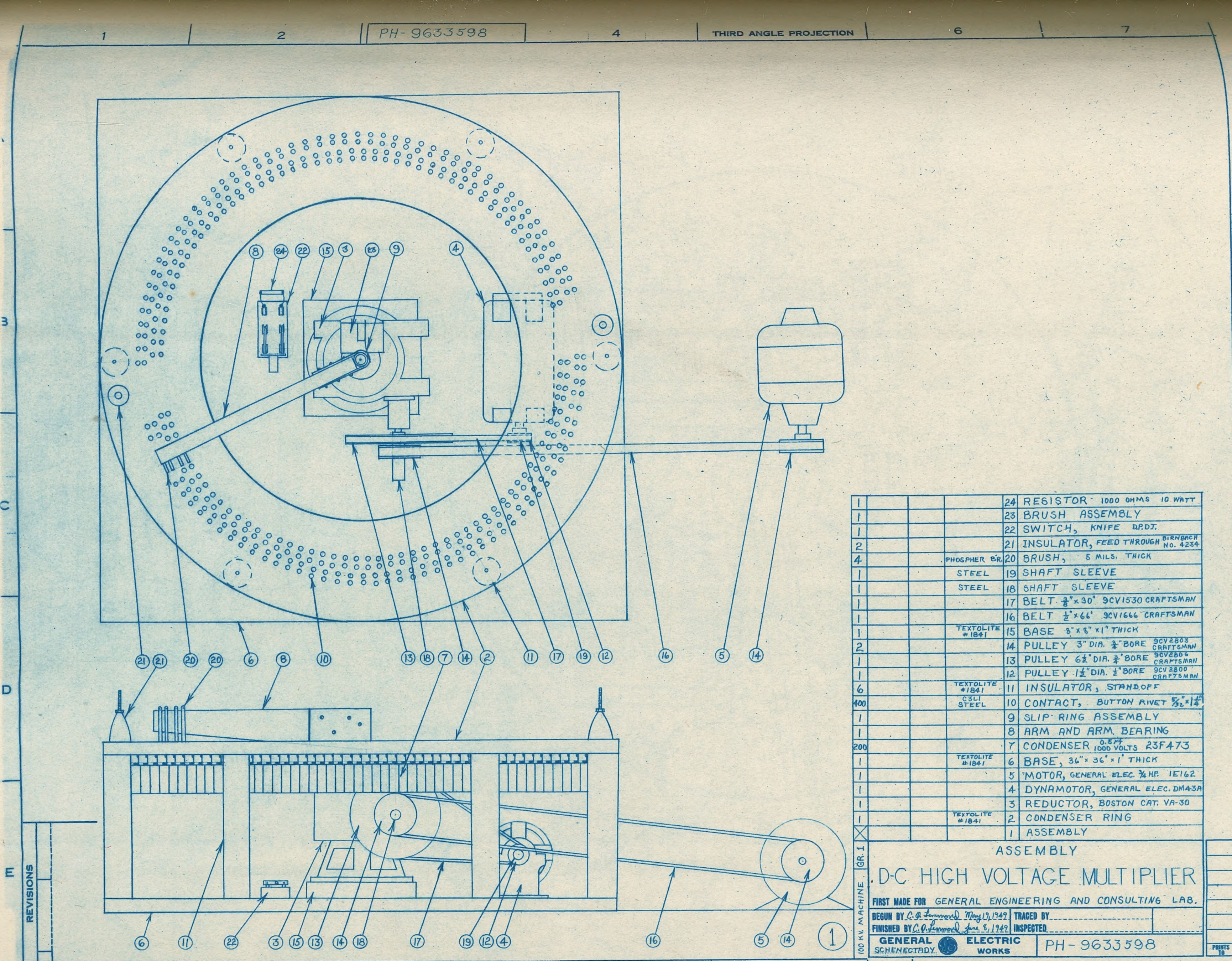
in a circular path with an arm sweeping over them and leaving the 1000 volt charge as it passed each capacitor.

In order to increase the spacing between the plus and minus output terminals, two sets of capacitors were used. One set of 100 capacitors was connected so that it built up from zero to full value, and the second set had reversed connections and reduced the voltage from 100,000 volts to ground. The output terminals are directly opposite each other on the capacitor ring. The capacitors were stacked in two rows to decrease the diameter of the ring. Drawing No. PH-9633598 shows this arrangement.

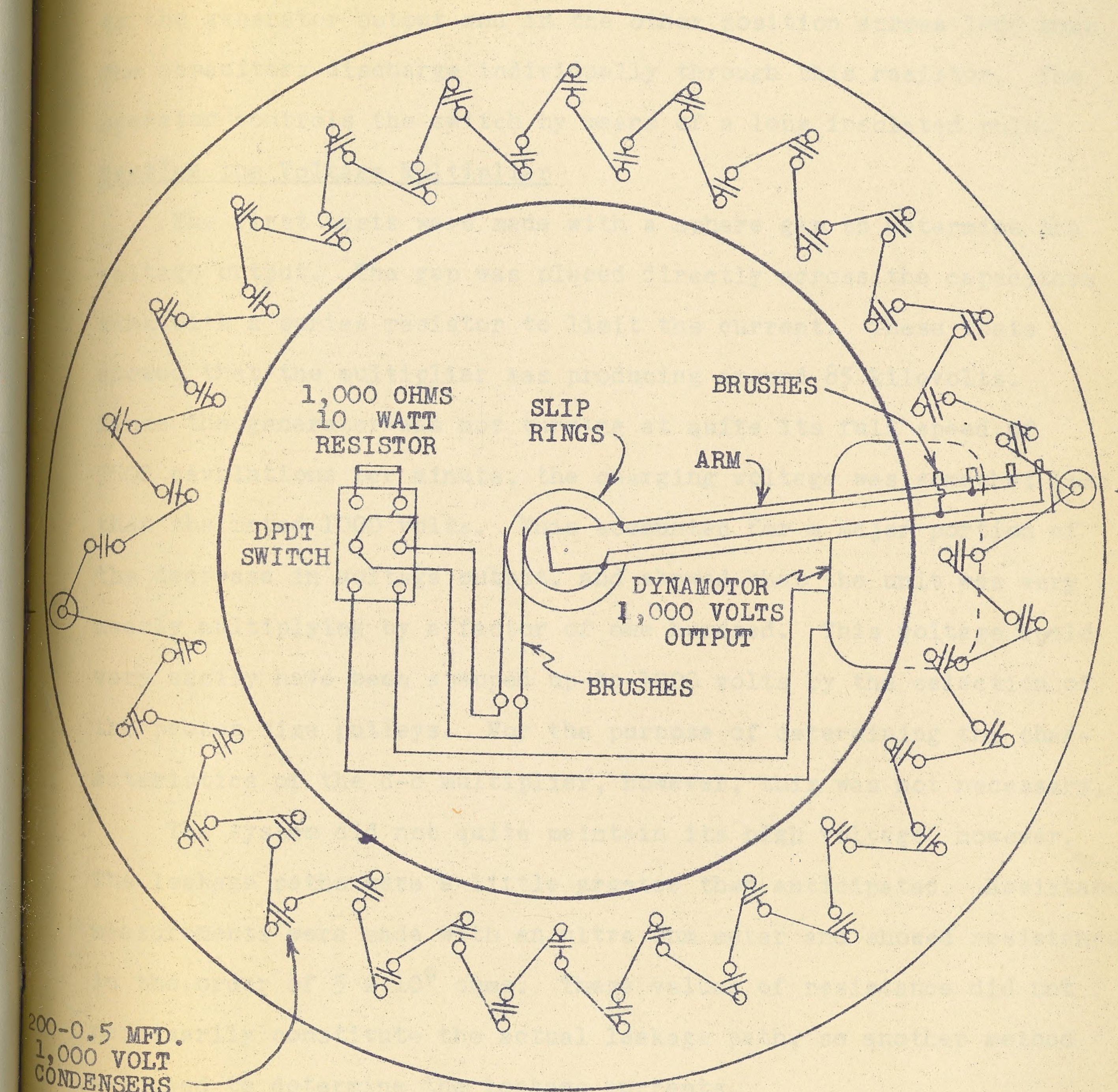
The charging arm sweeps over the capacitors at a rate of once per second. A gear reduction was required to reduce the speed of the drive motor to the desired speed. A Boston gear reductor was selected for this purpose. The whole unit is driven by a 3/4 horsepower motor which is mounted at a good distance from the capacitor ring. Two belts were employed; one for driving the gear reductor and the second to drive the generator.

The output of the generator reaches the charging arm by means of slip rings and brushes. The voltage is then connected to two sets of brushes which wipe over the contact points and charge the capacitors. The brushes are made of phosphor bronze and have knife-edge action. The wiring diagram is found on drawing No. KH-9633599. See photograph No. 1069461 for a view of the complete unit.

A means of discharging the capacitors after the machine has been in operation was found necessary. This was accomplished by inserting a double pole, double throw, knife switch in the circuit,



1				24	RESISTOR 1000 OHMS 10 WATT
1				23	BRUSH ASSEMBLY
1				22	SWITCH, KNIFE D.P.D.T.
2				21	INSULATOR, FEED THROUGH BIRNBACH NO. 4234
4			PHOSPHER BR.	20	BRUSH, 5 MILS. THICK
1			STEEL	19	SHAFT SLEEVE
1			STEEL	18	SHAFT SLEEVE
1				17	BELT 3/8" x 30" 9CV1530 CRAFTSMAN
1				16	BELT 1/2" x 66" 9CV1666 CRAFTSMAN
1			TEXTOLITE #1841	15	BASE 8" x 8" x 1" THICK
2				14	PULLEY 3" DIA. 3/4" BORE 9CV2803 CRAFTSMAN
1				13	PULLEY 6 1/2" DIA. 3/4" BORE 9CV2806 CRAFTSMAN
1				12	PULLEY 1 1/2" DIA. 1/2" BORE 9CV2800 CRAFTSMAN
6			TEXTOLITE #1841	11	INSULATOR, STANDOFF
400			C3LI STEEL	10	CONTACT, BUTTON RIVET 5/32" x 1 1/4"
1				9	SLIP RING ASSEMBLY
1				8	ARM AND ARM BEARING
200				7	CONDENSER 0.5 mf 1000 VOLTS 23F473
1			TEXTOLITE #1841	6	BASE, 36" x 36" x 1" THICK
1				5	MOTOR, GENERAL ELEC. 3/4 HP. 1E162
1				4	DYNAMOTOR, GENERAL ELEC. DM43A
1				3	REDUCTOR, BOSTON CAT. VA-30
1			TEXTOLITE #1841	2	CONDENSER RING
X				1	ASSEMBLY



KH-9633599

WIRING DIAGRAM D-C HIGH VOLTAGE MULTIPLIER	
DRAWN BY C. P. Lemmon April 28, 1949	INSPECTED BY
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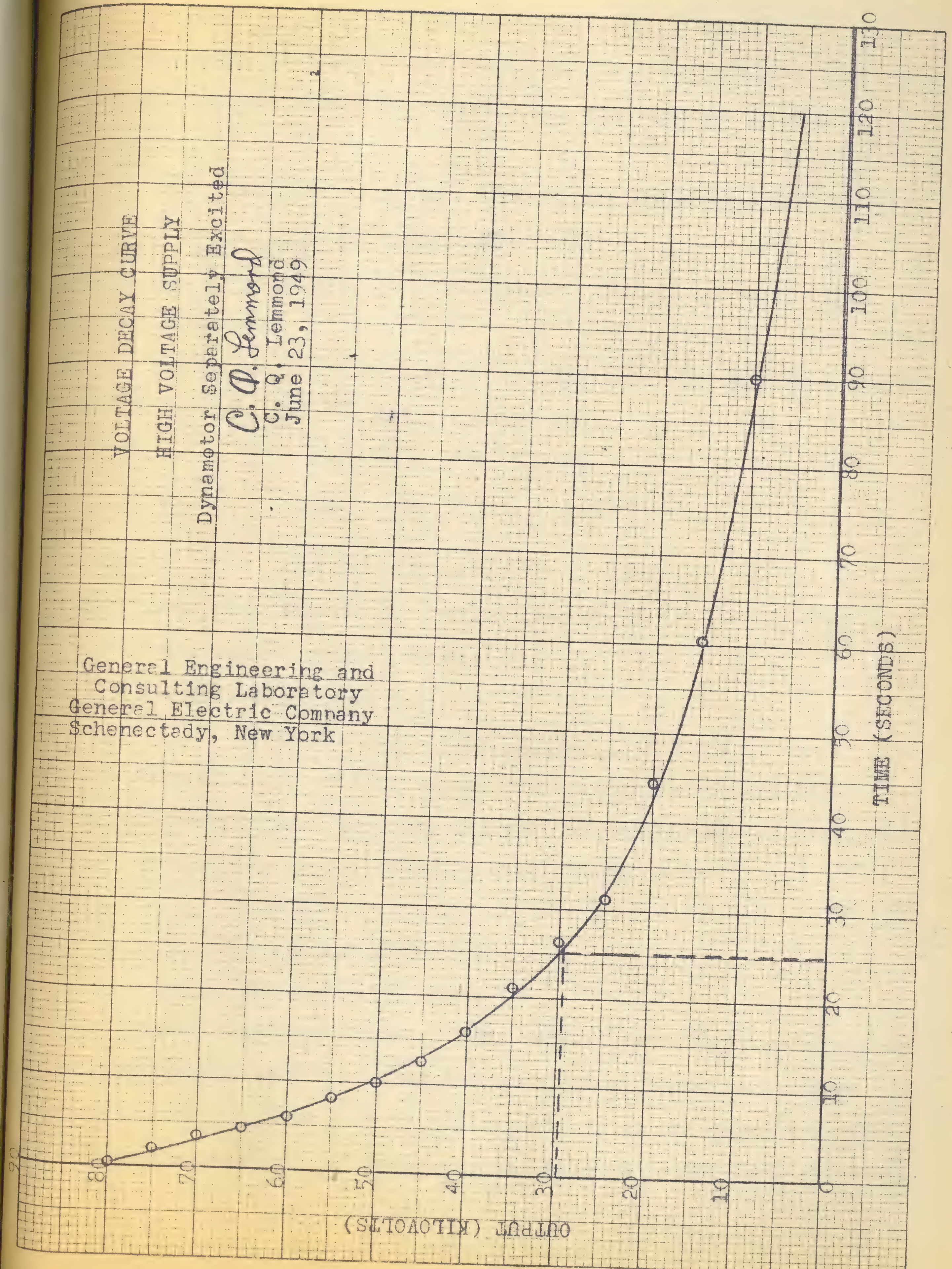
so that in one position the charging arm brushes are connected to the generator output and in the other position across 1000 ohms. The capacitors discharge individually through this resistor. The operator controls the switch by means of a long insulated pole.

<u>Testing the Voltage Multiplier</u>

The first tests were made with a sphere gap to determine the voltage output. The gap was placed directly across the capacitors tank with a series resistor to limit the current. These tests showed that the multiplier was producing around 85 kilovolts. Since the generator was not turning at quite its full speed of 7500 revolutions per minute, the charging voltage was somewhat less than the rated 1000 volts. This accounted for a major portion of the decrease in voltage output, and showed that the unit was very nearly multiplying by a factor of one hundred. This voltage could very easily have been stepped up to 1000 volts by the selection of the proper size pulleys. For the purpose of determining the characteristics of the d-c multiplier, however, this was not necessary.

The system did not quite maintain its high voltage, however. The leakage paths were a little greater than anticipated. Resistance measurements were made with an ultra ohm meter and showed resistances in the order of 5×10^9 ohms. These values of resistance did not necessarily constitute the actual leakage path, so another method was used to determine the leakage currents.

A curve was plotted of kilovolt output versus voltage decay time, beginning at the instant the charging voltage was disconnected. Curve No. KH-9636400 shows these data. The curve is exponential


VOLTAGE DECAY CURVE
HIGH VOLTAGE SUPPLY
Dynamotor Seperately Excited
C. Q. Lemmond
C. Q. Lemmond
June 23, 1949
General Engineering and
Consulting Laboratory
General Electric Company
Schenectady, New York
TIME (SECONDS)
0 10 20 30 40 50 60 70 80 90 100 110 120 130
OUTPUT (KILOVOLTS)
0 10 20 30 40 50 60 70 80 90

and the value of $1/\varepsilon$ of the total voltage corresponds to the voltage reached at a time equal to the time constant of the circuit.

At a time (t_1) equal to 1 second, the output was 80 kilovolts.

$$\frac{1}{\varepsilon} \times 80 = 29.43 \text{ kilovolts}$$

From the curve we find t_2 = 25 seconds for this corresponding value of output.

The value of the voltage at anytime after the switch was opened and the capacitors discharge started is:

$$e = E\varepsilon^{-\frac{t}{T}} = E\varepsilon^{-\frac{t}{t_2 - t_1}}$$

$$= 80\varepsilon^{-\frac{1}{-25-1}} = 80\varepsilon^{-0.0417}$$

$$= 76.96 \text{ kilovolts.}$$

This shows that the voltage varies from 76.96 to 80 kilovolts and a 3.04 kilovolt ripple is present.

The regulation will be:

$$\% \text{ Regulation} = \frac{80 - 76.96}{80} = 3.93\%$$

From this information we can also determine the effective leakage resistance. The time constant of the circuit is 24 seconds and the capacity is 0.01 microfarads. Therefore:

$$T = RC$$

$$24 = R \times 0.01 \times 10^{-6}$$

$$R = 2.4 \times 10^{9} \text{ ohms.}$$

Four 0.1 microfarad capacitors were connected in series across the voltage multiplier output and stabilized the voltage output considerably. The use of larger capacitors on the capacitor ring and the decrease of the leakage paths seem to be the best solutions

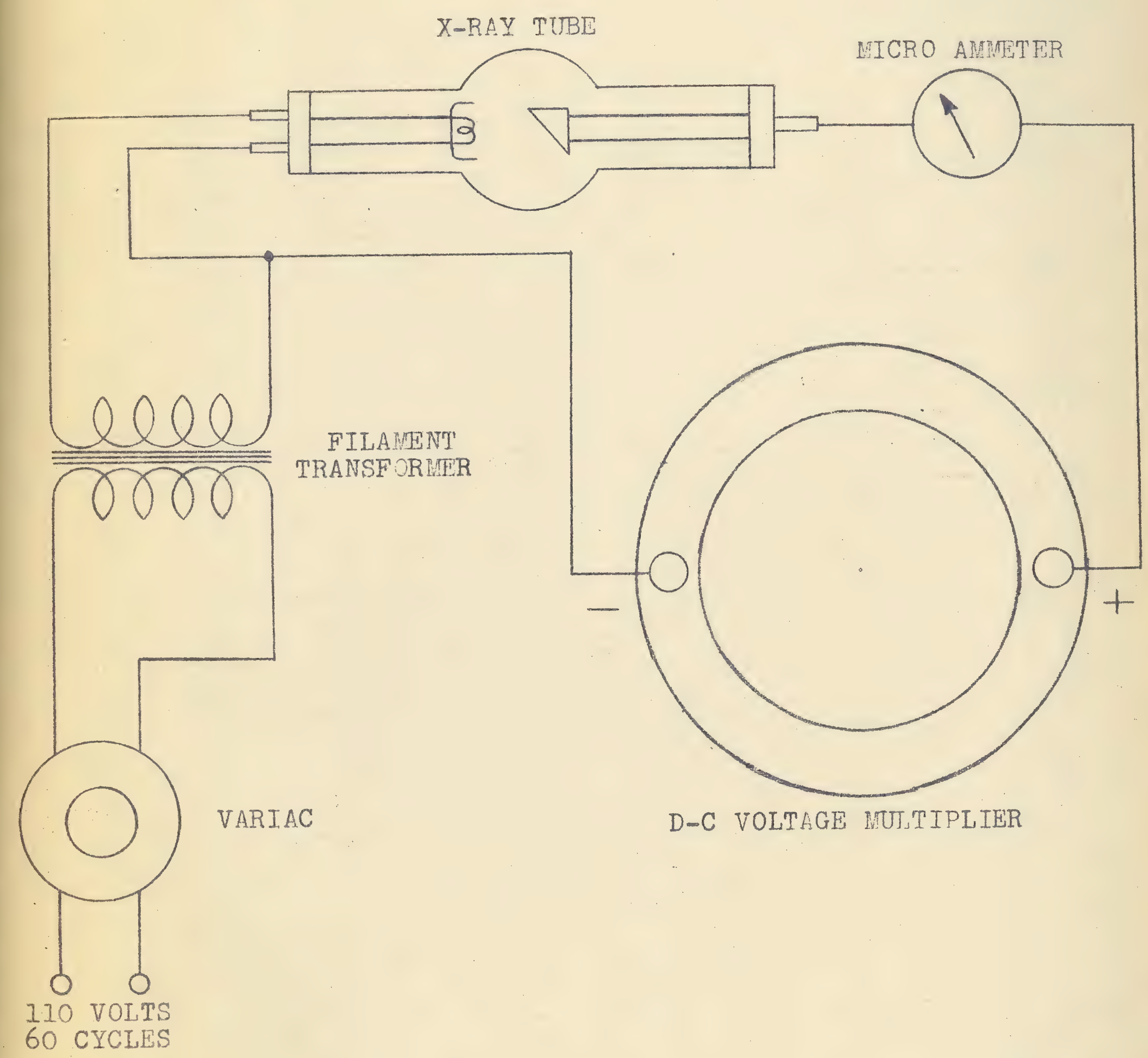
toward reducing the voltage ripple. The leakage could be lessened immensely by the choice of a material with a very high volume resistivity. Another approach would be to mount the capacitors by their cans rather than their terminals. The charging would be accomplished in a manner similar to that now employed.

The leakage current on the present design is approximately half of the load current permissible for a low voltage ripple. The leakage current can be materially decreased by the methods mentioned above and the system will be very practical.

X-Ray Tube Load

An x-ray tube (Coolidge Type 4UD) was used to load the system. It was connected as shown in drawing No. KH-9636401. A variac was used to vary the filament current which in turn controlled the anode current. A curve was plotted of plate current in microamperes versus radiation intensity in roentgens per hour. See Curve No. KH-9636402. The radiation intensity was measured at a distance of 24 inches from the x-ray tube target. As the load increased it reached a point where the voltage began to drop. When the current reached 250 microamperes, the voltage had dropped to a point where there was no longer a readable x-ray output.

The x-ray tube was used for obtaining additional data. The load current was varied and the decrease in output voltage noted. The voltage drop for the current drain permissible is very low as is shown in curve No. KH-9636403. From this curve it is seen that if the current requirements are very low, the voltage regulation becomes very good.



KH-9636401

CIRCUIT DIAGRAM
X-RAY TUBE
EXCITED BY D-C VOLTAGE MULTIPLIER HIGH VOLTAGE SUPPLY

DRAWN BY C. P. Lemmond June 27, 1949 | INSPECTED BY

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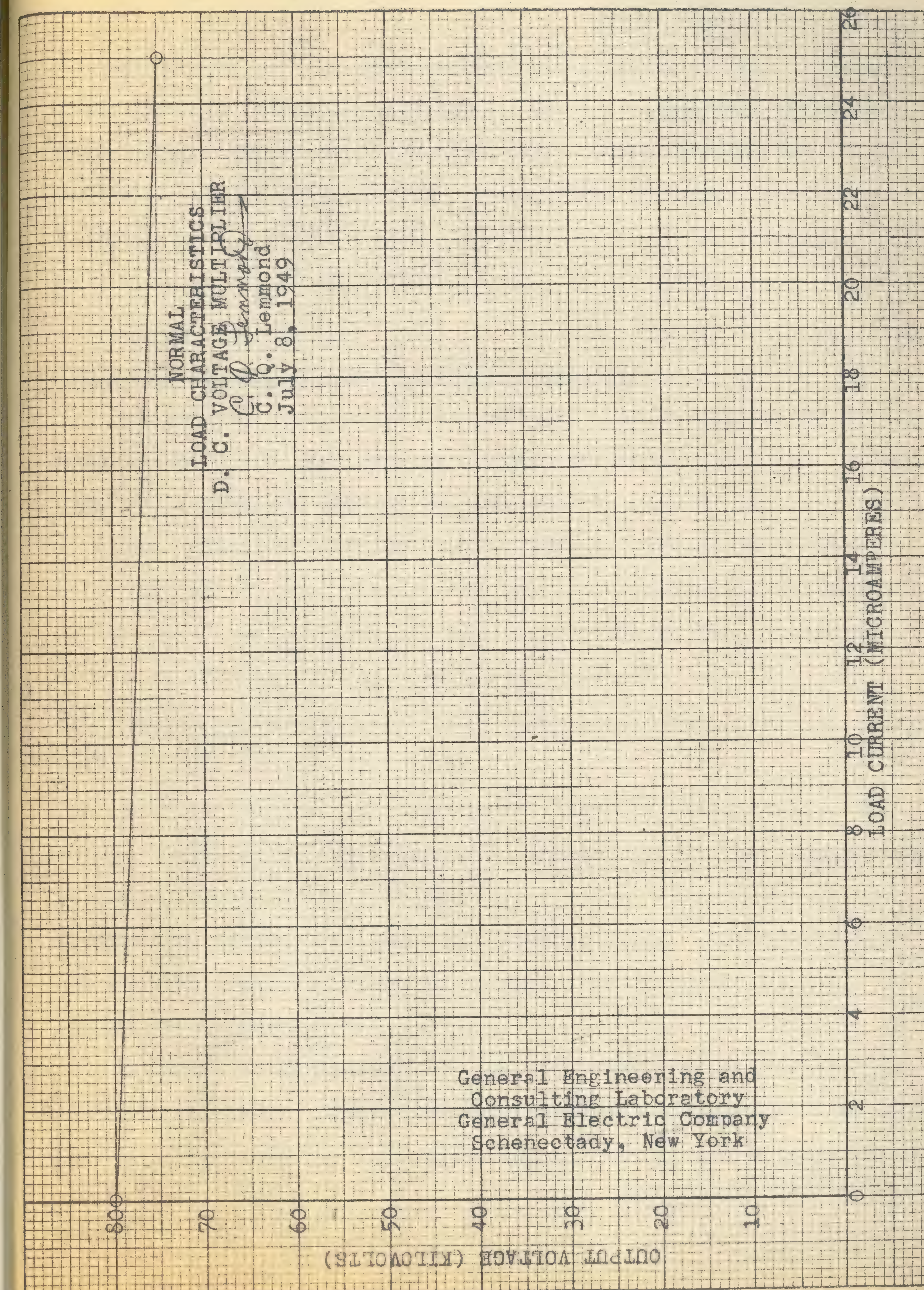

NORMAL
LOAD CHARACTERISTICS
D. C. VOLTAGE MULTIPLIER
C. Q. Lemmond
C. Q. Lemmond
July 8, 1949
General Engineering and
Consulting Laboratory
General Electric Company
Schenectady, New York
LOAD CURRENT (MICROAMPERES)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
OUTPUT VOLTAGE (KILOVOLTS)
80
70
60
50
40
30
20
10

The curve was extended to show the drop in voltage at higher load currents. This information is shown on curve No. KH-9636404. Here we see that the voltage output may be cut in half and a load of 250 microamperes permitted. The machine therefore can be operated at much higher current drains, but at lower voltages. This characteristic should provide additional usages for the d-c voltage multiplier.

Photomultiplier Tube and the Voltage Multiplier

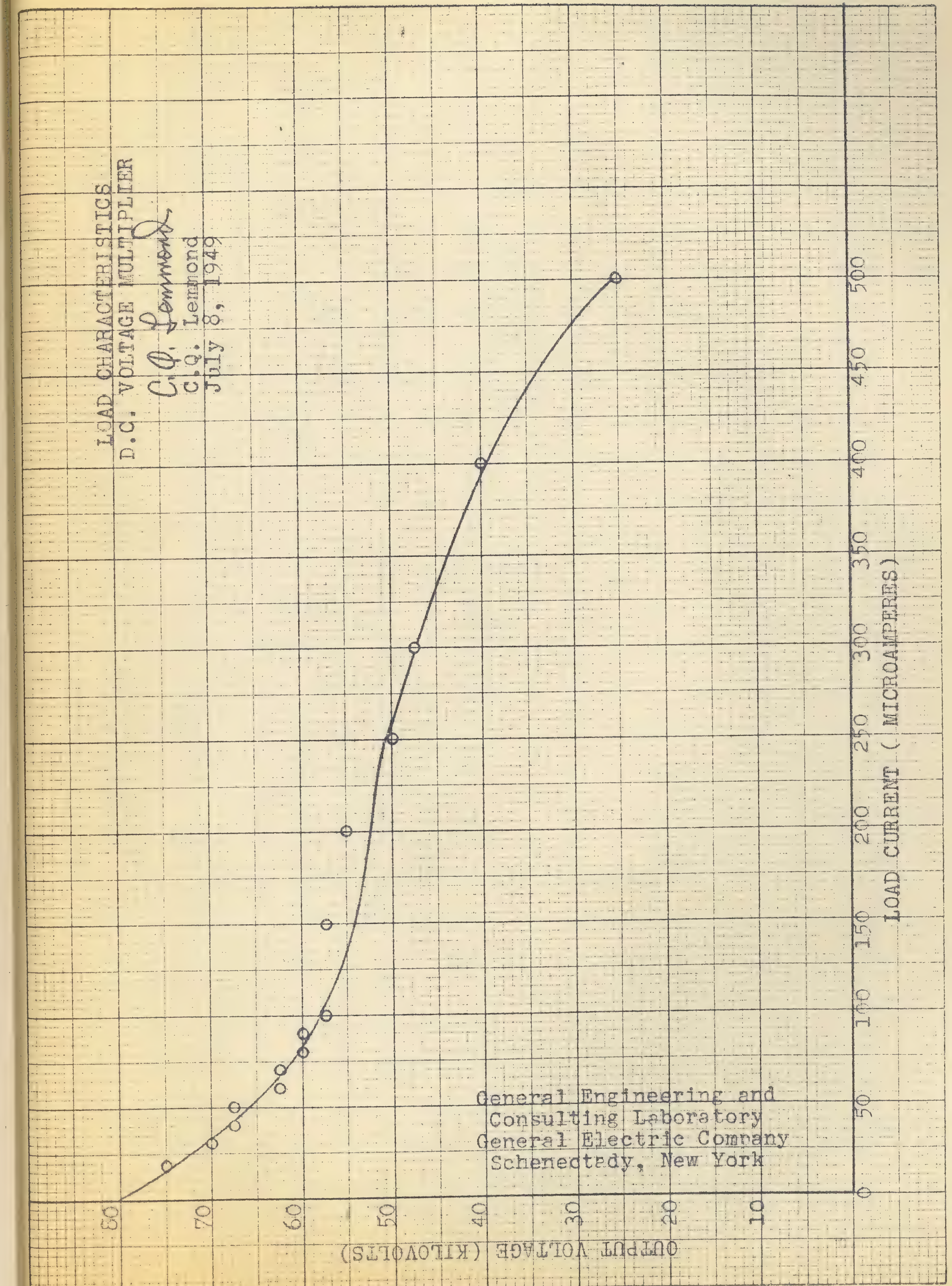
A small unit using the same principle as described was used to provide the dynode voltages for a photomultiplier tube. The circuit diagram is shown on drawing No. KH-9636405.

The voltage multiplier in this case stepped up the voltage by a multiple of ten. The individual dynode voltages were tapped off of the capacitor ring so that they increased from dynode to dynode by 100 volts. This application was very practical and produced an extremely stable voltage as the current drain was very small.

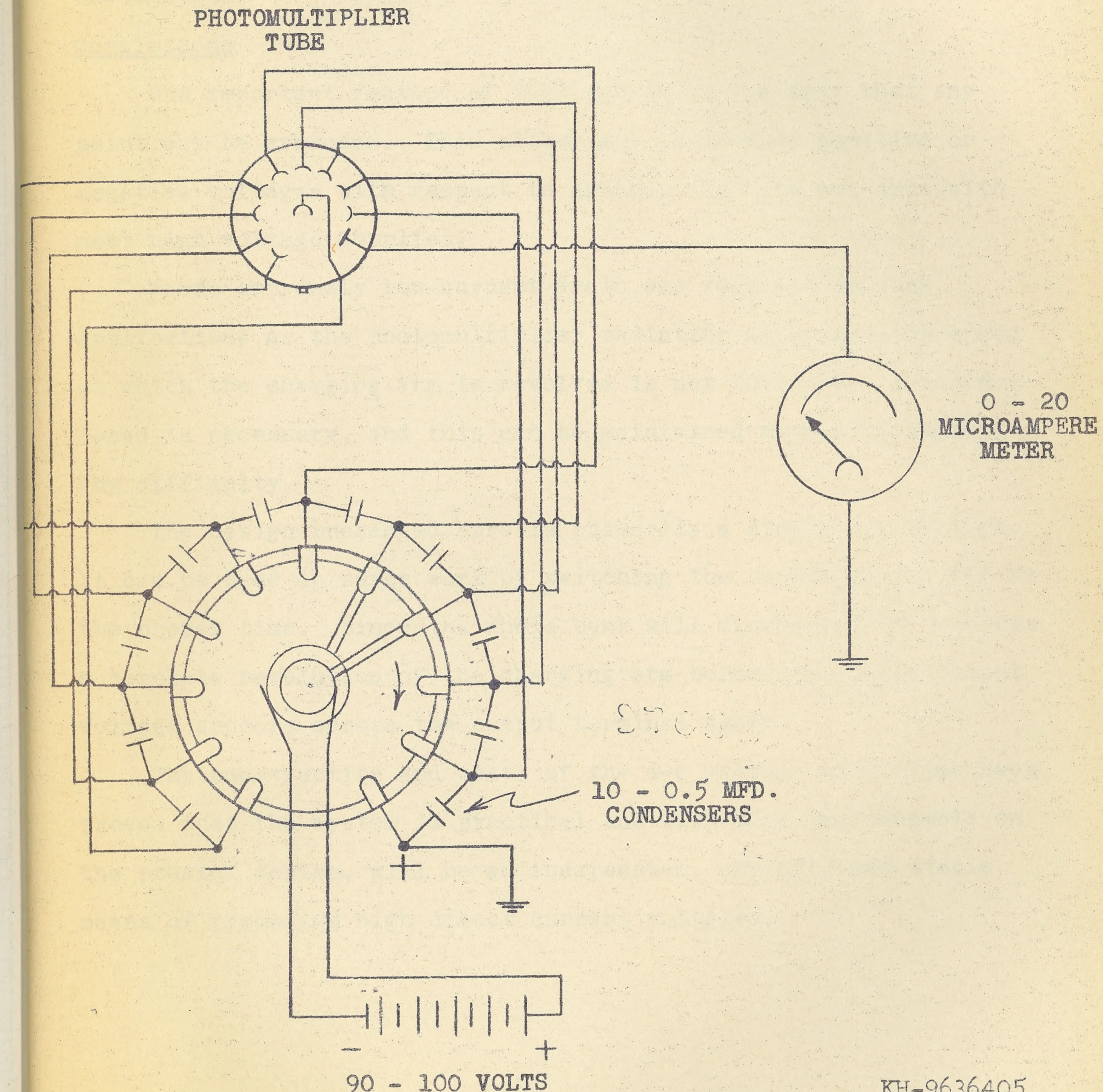
An experimental radiation survey instrument was built using the photomultiplier tubes to record the amount of light produced in a phosphor when in the presence of radiation. The output of the photomultiplier was read on a microampere meter. This instrument has possibilities as a high intensity radiation detector.

Particle Accelerator

A promising application of the d-c voltage multiplier is its use as a voltage supply for a heavy particle accelerator. If ten of the units described were connected in series, one million volts


LOAD CHARACTERISTICS
D.C. VOLTAGE MULTIPLIER
C.Q. Lemmond
C.Q. Lemmond
July 8, 1949
General Engineering and
Consulting Laboratory
General Electric Company
Schenectady, New York
LOAD CURRENT (MICROAMPERES)
0 50 100 150 200 250 300 350 400 450 500
OUTPUT VOLTAGE (KILOVOLTS)
80 70 60 50 40 30 20 10

H-9636405 THIRD ANGLE PROJECTION



KH-9636405

CIRCUIT DIAGRAM
PHOTOMULTIPLIER TYPE RADIATION SURVEY METER
WITH D-C VOLTAGE MULTIPLIER HIGH VOLTAGE SUPPLY

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would be produced, and by increasing the unit voltage to 200 kilovolts, two million volts would be available. See drawing No. KH-9636406.

Conclusions

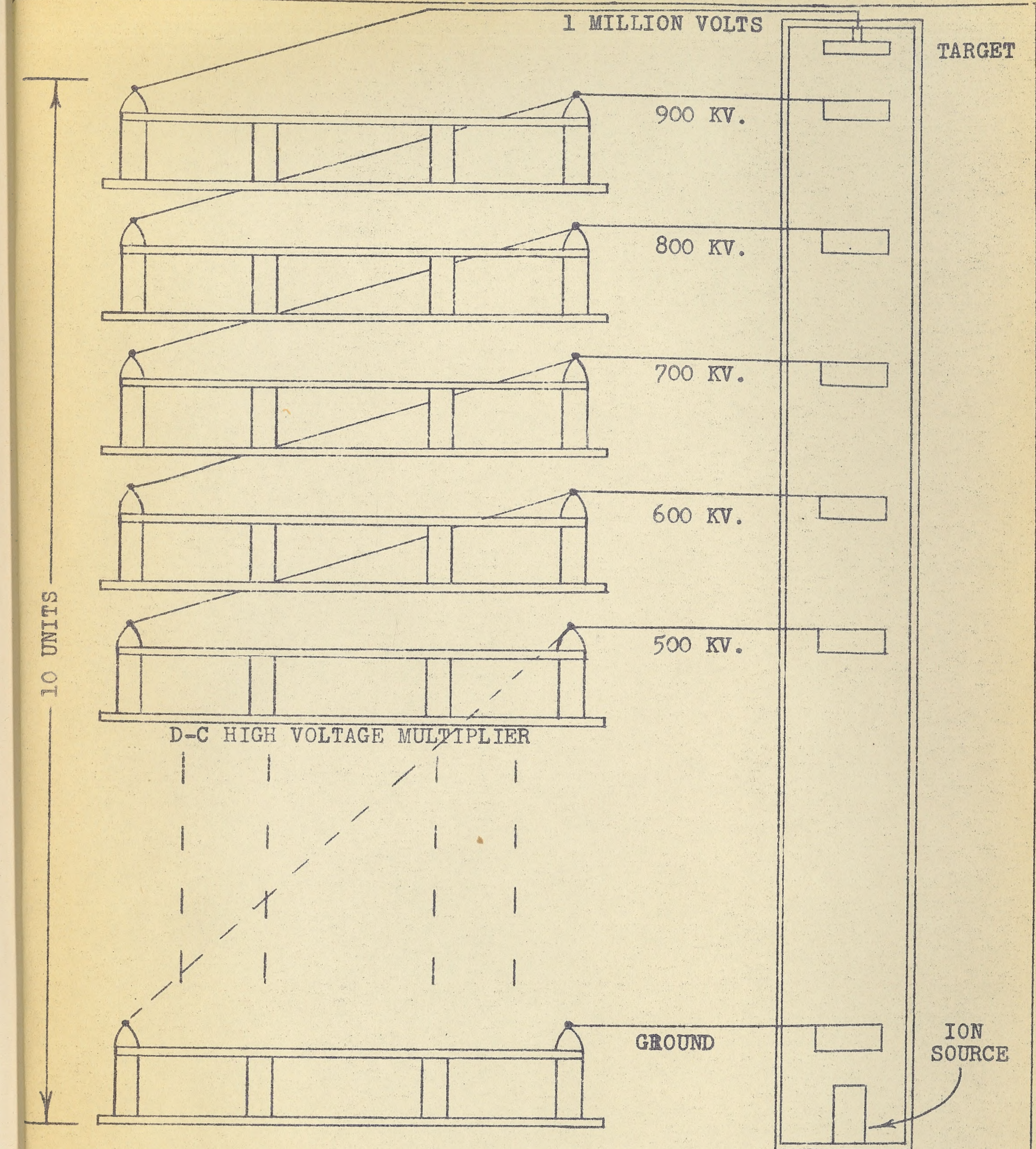
One important feature of this system is the fact that any point may be grounded. This allows one to produce positive or negative voltages with respect to ground. Such is not true with most high voltage supplies.

Where extremely low current drain are required in such applications as the photomultiplier radiation detector, the speed at which the charging arm is revolved is not critical. A minimum speed is necessary, and this can be maintained manually without any difficulty.

The design presented here is primarily a steady d-c voltage. It can be used in surge work by switching the output on and off at the proper time. Since the whole bank will discharge, it requires a complete revolution of the charging arm before the total output voltage appears across the output terminal again.

The construction and tests of the d-c voltage multiplier have proved that the system is practical and with some improvements on the present design, will be an inexpensive, compact, and stable means of producing high direct current voltages.

KH-9636406 THIRD ANGLE PROJECTION



KH-9636406

CIRCUIT DIAGRAM
PARTICLE ACCELERATOR
USING MULTIPLE D-C VOLTAGE MULTIPLIER VOLTAGE SUPPLY

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